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PROBLEMS IN STRATIGRAPHY ALONG THE ROCKY MOUNTAIN TRENCH

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In an investigation of the structure of the Rocky Mountain trench, from Gateway, Montana, to Golden, British Columbia,[1] the writer came in contact with some of the stratigraphic problems of the Canadian Cordillera. For determination of fossils and for helpful criticism he wishes to acknowledge his indebtedness to Dr. Stuart Weller.

STRATIGRAPHIC SERIES ALONG THE ROCKY MOUNTAIN TRENCH

From the fossils collected at various localities and the sections which have been previously made of the trench, it was possible to map with some degree of accuracy a large part of the zones flanking this great valley (Fig. 1). There are two principal series of rocks represented. One of these is dominantly clastic, the other dominantly limestone. The former contains many metamorphic varieties of shales, sandstones, and conglomerates, but the metamorphism is not extreme. Limestone is not lacking in the clastic series, but most of it is in thin bands. (For convenience this series will be termed the "clastic series.")

The age of these formations is somewhat problematic. In those places where it has been studied hitherto, it has been generally considered pre-Cambrian, but fossils found recently in one locality have shown part of it at least to be as young as Lower Cambrian.[2] That the series is older than Upper Cambrian is indicated by the following points: (1) In a number of places it was found underlying Upper Cambrian formations, and nowhere has it been observed overlying formations containing Paleozoic fossils. (2) It is in general metamorphosed more than formations of the limestone series.

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[1] F. P. Shepard, *Jour. Geol.*, Vol. XXX (1922), p. 130.

[2] S. J. Schofield, *Science*, Vol. LIV (1921), p. 666.

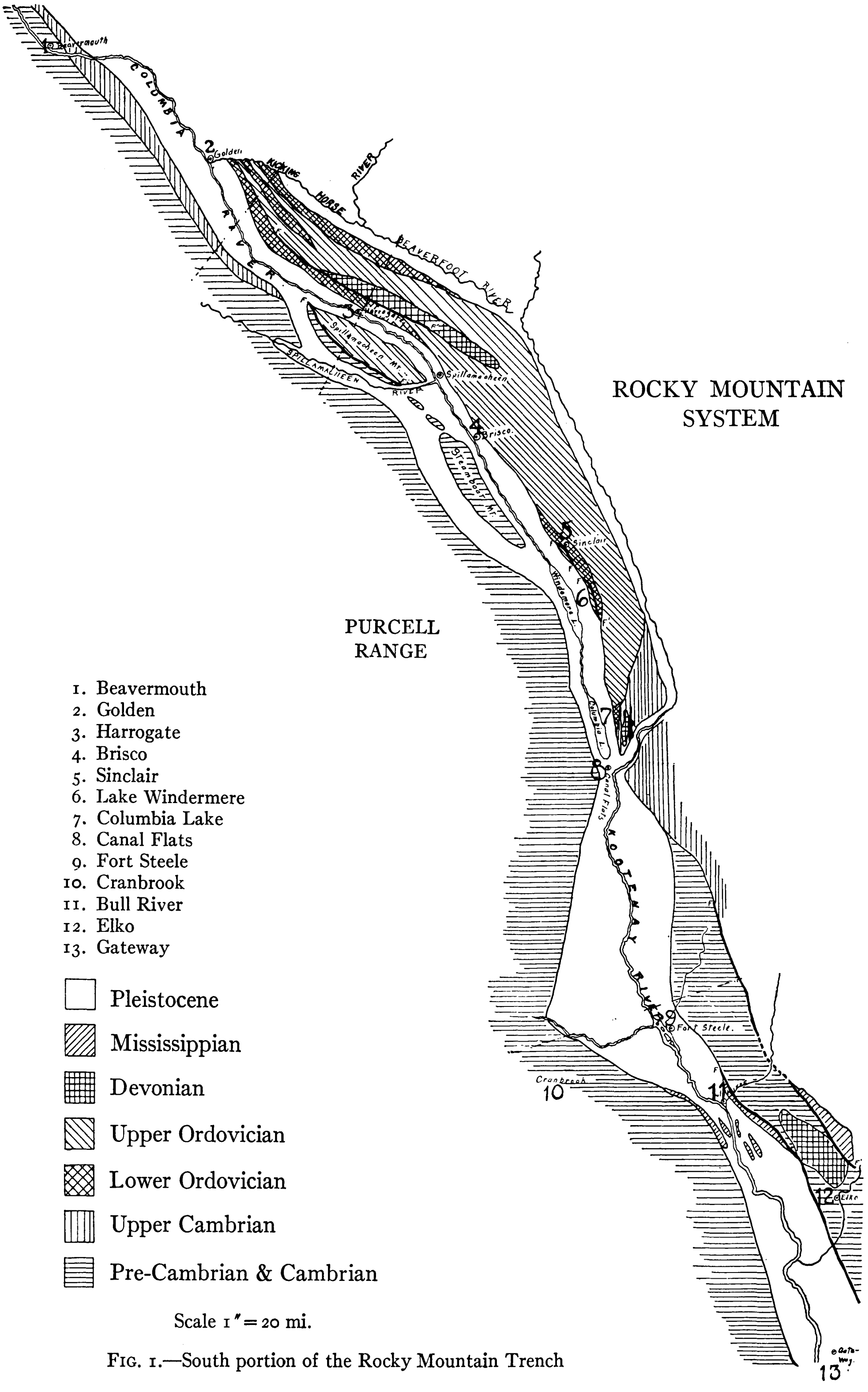

FIG. 1.—South portion of the Rocky Mountain Trench

(3) Fossils were found only in one place, while in the other series they were abundant. No attempt has been made to divide or correlate the different members of the clastic series, because of the great difficulty and the extremely detailed work necessary for classification of unfossiliferous formations in a folded region. A part of it is probably pre-Cambrian.

In the limestone series fossils of the following ages have been found: Upper Cambrian, Lower Ordovician, lower Richmond, upper Richmond, Upper Devonian, and Mississippian. Also the Middle Cambrian horizon at Elko might be considered as part of the "limestone series." Other horizons, including portions of the Silurian, are possibly present. Disconformities are common, showing that there was considerable oscillation of the areas of active deposition. Angular unconformities have not been found but may occur.

Stratigraphic sections were made at several localities along the trench and some of the more representative have been combined into a generalized section (Fig. 2). This section consists chiefly of formations found in the vicinity of Sinclair Springs.

Upper Cambrian and Lower Ordovician.—No stratigraphic break has been observed between the Cambrian and Ordovician in the northern portion of the trench visited. Fossils were collected which have been identified by Dr. Walcott as belonging at the top of the Upper Cambrian, and above this is a horizon containing a fauna identified by Dr. Raymond as corresponding to the base of the Ordovician in Europe.[1] Walcott identified the following species:

Dicellomus sp.
Agnostus sp.
Agnostus sp.
Crepicephalus? fragments of cephalon
Ptychaspis cf. striata Whitfield

The species identified by Dr. Raymond included:

Lingulella moosensis
L. allani
Obolus molisonensis
Eorthis desmopleura
E. sp. (ind.)
Cyphaspis brevimarginata
Hemigyraspis mcconnelli
H. carbonensis
Megalaspis shepardi sp. nov.
Dalmanella hamburgensis

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[1] P. E. Raymond, *Am. Jour. Sci.*, fifth series, Vol. III, p. 204.

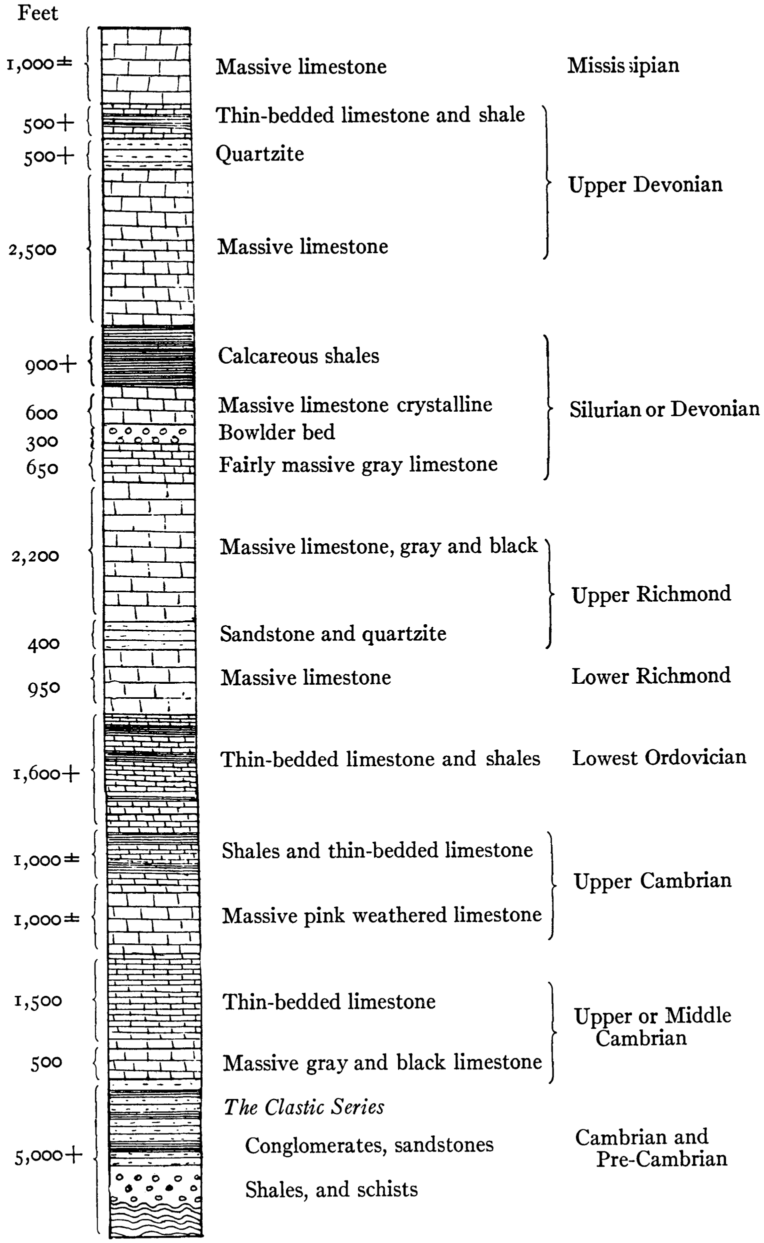

FIG. 2.—Generalized section along the Rocky Mountain trench

Syntrophia nundina	Symphysurus cleorus
Raphistoma nasoni	S. elongatus
Arthrorachis sp. ind.	Menocephalus sp. ind.
Hystricurus tuberculatus	

According to Raymond this is a typical Ceratopyge fauna, comparable to that at the base of the Ordovician in Europe. It has been found in several other localities in the west directly overlying the Upper Cambrian, and Dr. Raymond thinks that it implies the absence of the Ozarkian series from the west.

Upper Ordovician and Silurian.—Comparing the section made by Allen[1] along the main line of the Canadian Pacific with that of the trench, there are seen to be some resemblances but several important differences.

SECTION ALONG THE CANADIAN PACIFIC

(After Allen)

System	Formation	Thickness	
		Feet	Meters
Mississippian........	Lower Banff shale Lower Banff limestone (partly Devonian)	1,200 1,500	366 457
Devonian...........	Intermediate limestone Sawback limestone (Devonian?) (thickness, 1,128 m.)	1,800	548 ....
Silurian............	Halysites beds	1,850	563
Ordovician..........	Graptolite shale Goodsir shale	1,700 6,040	518 1,841
Upper Cambrian.....	Ottertail limestone Chancellor shales Sherbrooke limestones Paget limestones Bosworth limestones	1,725 4,500 1,375 360 1,855	526 1,372 419 110 565
Middle Cambrian....	Eldon limestones Stephen limestone-shale Cathedral limestones	2,728 640 1,595	831 196 486
Lower Cambrian.....	Mt. Whyte sandstone shale St. Piran quartzite Lake Louise shale and sandstone } Rocky Mountains	....	....

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[1] J. A. Allen, *Can. Geol. Surv. Guidebook No. 8,* Part 2, p. 120.

In Allen's section the Halysites limestone is placed in the Silurian. This formation, however, contains the same fauna that is found in the formation considered upper Richmond in the accompanying section (Fig. 2). The fauna contains the corals which are generally typical of the Silurian, namely Halysites catentulatus, Favosites, but these are also known to occur in the west in formations which are generally considered to be Ordovician,[1] as for example in the upper portion of the Big Horn limestone. The fauna also includes characteristic Upper Ordovician (Richmond) brachipods among which a form of Rhynchotrema capax is most common. Whether Silurian strata are actually present in the section is open to question. In two localities, overlying the upper Richmond and underlying formations of Devonian age, there are several thousand feet of limestone and shale in which no fossils were found. In one locality the upper Richmond is overlain by a bowlder bed which strongly suggests tillite,[2] and as Silurian tillites have been reported in southeastern Alaska[3] at a similar horizon, it is possible that this formation is of the same age.

Devonian.—The Devonian seas probably invaded the Rocky Mountain trench from two directions. An invasion from the south by an arm of the Jefferson seas, which covered most of the Rocky Mountain region of the United States, is believed to have occupied the southern portion of the trench. Formations of this age have been found by Daly at the international boundary line[4] and again farther north near Elko and Canal Flats by Schofield.[5] The fossil species collected from this formation, which are also known to be present in the Jefferson limestone are Spirifer englemani and S. utahensis, both of which are guide fossils for the Jefferson.

Highly fossiliferous Devonian strata were also observed a mile east of Harrogate in the Beaverfoot Range. The fauna is unlike that of the Jefferson limestone, but is related to that of the Devonian formations off the MacKenzie River district to the north, an occurrence which suggests the extension of an arm of the MacKenzie Devonian sea into the northern part of the trench. The fossil forms in this fauna which are also known in the MacKenzie Devonian include the following species:

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[1] N. H. Darton, *Bull. Geol. Soc. of Am.*, Vol. XV, p. 399.

[2] F. P. Shepard, *Jour. Geol.*, Vol. XXX (1922), p. 89.

[3] E. Kirk, *Am. Jour. Sci.*, fourth sec. (September, 1918), p. 511.

[4] R. A. Daly, *Geol. Surv. Can. Mem. 38*, p. 115.

[5] S. J. Schofield, *Geol. Surv. Can. Mem. 76*, p. 53.

Martinia meristoides
Reticularia fimbriata
Schizophoria macfarlini
S. striatula
Spirifer tulia
Atrypa reticularis
Astraespongia hamiltonensis
Heliophyllum halli

a faunal group which suggests late Middle or early Upper Devonian age.

Whether this invasion from the MacKenzie basin was contemporaneous with that from the south, with the two submergences separated by a land barrier in the Lake Windermere district, is not established, but the invasion from the north was probably somewhat later than that from the south.

Mississippian.—The Mississippian is known to occur only in the southern portion of the trench in the vicinity of Wardner and Bull River, where it was discovered by Schofield.[1] Dr. Raymond identified the following species:

Camarophoria explanata
Camaroechia cf. C. metallica
Composita madisonensis
Cleiothyridna crassicardonalis
Spirifer cf. S. centronatus
Productella cooperensis

RELATION OF PRE-CAMBRIAN TO CAMBRIAN

The stratigraphic relation of the Cambrian sediments to the pre-Cambrian formations in the Canadian Cordillera has been the subject of considerable discussion. Daly considers the two series to be essentially conformable, while Walcott and Schofield think them unconformable.

The situation along the main line of the Canadian Pacific is well summed up by Daly in his report of the "Reconnaissance between Kamloops and Golden."[2] The thick lower Cambrian fossil-bearing members have at their base a conglomerate (the Fairview formation). Below this the Hector Shale is considered to be pre-Cambrian. Walcott[1] believes that between these two formations there is an unconformity, shown by the following: (1) The overlying conglomerates contain fragments of the Hector shale. (2) Slight hollows in the Hector shale are filled with thin sandstone lenses. (3) The underlying Beltian (Proterozoic) formation varies in character at the contact from place to place. (4) The sediments seem to change from brackish water in the Beltian, to marine in the Cambrian. (5) Allen's discoveries of the contact between the Hector shale and the Fairview formation showed apparent conformity in one place, while in two others discordance of dip of 4°.

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[1] S. J. Schofield, *Geol. Surv. Can. Mem. 76,* p. 57.

[2] R. A. Daly, *Geol. Surv. Can. Mem. 68,* pp. 87–93.

Daly makes the following reply to these arguments: (1) The fragments of the Hector shale in the overlying Fairview conglomerate are all angular and do not show a significant time break. (2) The Fairview is nearly identical with formations occurring at various horizons in the pre-Cambrian. (3) The sandstone beds in the upper surface of the Hector are merely lenses which are common elsewhere in the Beltian. (4) The discordance of dip seen between the Hector and the Fairview can be explained by irregularities in uplift as such are seen in continuous sedimentary series in many localities. (5) The Selkirk series is divided on lithological grounds into Cambrian and pre-Cambrian with the dividing plane in the Ross quartzite, where there is no sign of unconformity.

Daly's first four points appear to be sound. Walcott's arguments for an unconformity lack proof that a time break is represented. There might well have been a change in the conditions of sedimentation without unconformity. In the natural order of clastic sedimentation it is to be expected that there will be some stirring of older sediments by changes in the activity of the currents. In the "clastic series" along the west side of the trench many examples of such disturbances are found. It seems that more evidence is necessary here to warrant the conclusion of an unconformity of importance between the two systems. Minor disconformities are of course present in great numbers in most thick sedimentary series, especially if there are clastic sediments.

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[1] C. D. Walcott, *Smithsonian Misc. Coll.*, Vol. LVII, p. 343.

In regard to Daly's fifth point concerning the Selkirk series, recent evidence shows that the age of the series is very uncertain.[1] As stated above, Daly places the dividing line between the Cambrian and the pre-Cambrian in the Ross quartzite, because of lithological resemblances of the sequence of formations in the Canadian Rockies and the Selkirks, but the discovery of upper Paleozoic fossils in the Laurie formation, which underlies the Ross quartzite formation by 12,650 feet and is separated from it by the Nakimu limestone and the Cougar quartzite, disproves this conclusion.

A recent observation further complicates the situation.[2] The Cougar quartzite was found underlying the Upper Cambrian shales and limestones on the west side of the trench at Golden, and, while a detailed study of the contact was not made, it appears probable that there was at least no angular unconformity separating the two formations. Therefore one discovery places the Cougar formation above upper Paleozoic fossils and the other places it below the Upper Cambrian. It seems probable that the series in the Purcell Range is not of the same age as that in the Selkirks, a conclusion which seems more likely when it is considered that the section in the Purcell Range exhibits only a part of two of the formations which are present also in the Selkirks (Fig. 3).

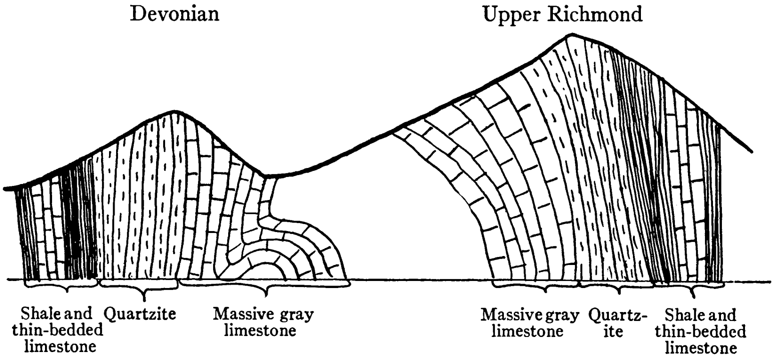

FIG. 3.—Section at Harrogate

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[1] L. D. Burling, *Bull. Geol. Soc. Am.*, Vol. XXIX, p. 146.

[2] F. P. Shepard, *Jour. Geol.*, Vol. XXX (1922), p. 146.

In the southern part of the trench Daly and Schofield are not in agreement as to the dividing line between the Cambrian and the pre-Cambrian. In Daly's "Forty-ninth Parallel Survey" the division between the Cambrian and the Beltian was placed within the "clastic series" between the Altyn formation below and the Hefty formation above.[1] This report was based on reconnaissance work in the field, and the division of the unfossiliferous formations was necessarily quite arbitrary. Schofield's more detailed work in the Cranbrook area[2] made changes in Daly's classification and produced more evidence concerning the age of the unfossiliferous series. He found Middle Cambrian fossils in the Burton formation near Elko, and below this, while there are no angular unconformities, there are marked signs of disconformity. There is a thin basal conglomerate at the base of the Middle Cambrian, and the surface of the Roosville formation beneath is somewhat weathered. From these facts Schofield concluded that there is an unconformity at the top of the Lower Cambrian, and placed the Roosville in the pre-Cambrian. Since the Roosville is the highest member of the "clastic series" (which is represented), this places all of that series in the pre-Cambrian. Recently, however, Colonel Pollin discovered a remarkably fine trilobite fauna in a formation which is probably lower than the Roosville. According to Walcott the fossils indicate a horizon at the top of the Lower Cambrian. Therefore the extent of the disconformity near Elko is minimized, and incidently Daly's original dividing line between the Cambrian and the Beltian is more nearly correct than that of Schofield.

However, Schofield has again attempted to find an unconformable relation between the Cambrian and the pre-Cambrian.[3] His evidence for this includes: (1) The thickness of sediments of the Siyeh formation between the Purcell lava and the basal conglomerate of the Lower Cambrian, varies from a few feet to 300 feet. (2) The lithological and metamorphic contrast above and below is marked. (3) Basal conglomerates of the Cambrian have rounded fragments of the underlying argillites.

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[1] R. A. Daly, *Geol. Surv. Can. Mem. 38*, p. 179.

[2] S. J. Schofield, *Geol. Surv. Can. Mem. 76*, pp. 41–52.

[3] S. J. Schofield, *Science*, Vol. LIV, p. 666.

This evidence does not necessarily place the underlying Siyeh formation in the pre-Cambrian. That the Olenellus horizon is not nearly at the base of the Cambrian is shown by the great thickness of Lower Cambrian below the Olenellus horizon in the Waucobian of California. Whether the length of the time bridged in this disconformity is sufficient to place the underlying formations in the Beltian, is open to doubt for the following reasons: (1) The degree of metamorphism varies greatly in members of the same age in the Purcell series. (2) The difference in the thickness of the Siyeh formation is not important, because of its clastic nature. (3) The occurrence of the conglomerate does not prove an unconformity, as conglomerates are common in the "clastic series." (4) Since there are great abundance and all varieties of argillites in the "clastic series" the fragments of argillites in the Cambrian conglomerates may have come from argillites other than those directly underlying the conglomerate. In general it may be said that minor unconformities are to be expected in a series of this sort, and their significance is not great. Since the contact of the Cambrian on the pre-Cambrian has been especially well studied, it is not surprising that minor unconformities should be found at some horizon not far below the lowest horizon that is known to be fossiliferous.

From observations on the relation of the "clastic series" to the "limestone series" farther north in the trench, new but rather incomplete evidence was found of the relation between the older series and the Upper Cambrian limestones (the base of these limestones may be Middle Cambrian). At Premier Lake, below what are probably the Upper Cambrian limestones, there is a series of argillaceous quartzites and shales. While no accurate measurement of the series was made, it was estimaetd to be at least 5,000 feet thick. As the series was examined in several places and was found to be quite similar in character in all of them, the condition of sedimentation is thought not to have varied in any important degree. This series is probably, at least in part, of the same age as the Purcell and Galton series farther south. The Purcell series is only 15 miles to the south in the Fort Steele region, and appears to be traceable this far north. The clastic nature of the deposits as against the limey deposits of the Upper Cambrian (and perhaps Middle Cambrian) indicates that there was variation in the character of the sedimentation in the Cambrian. In the vicinity of Parsons the Upper Cambrian is somewhat argillaceous, but the base of the Ordivician is mostly limestone.

If the Beltian is actually present at the base of the "clastic series," it seems as though the greatest change during the Beltian and Cambrian times was a change from semiterrestrial and near shore deposits to deposits in clear broad seas. Probably this change is of more importance than any minor unconformities that may exist below the lowest rocks which are known to contain fossils.

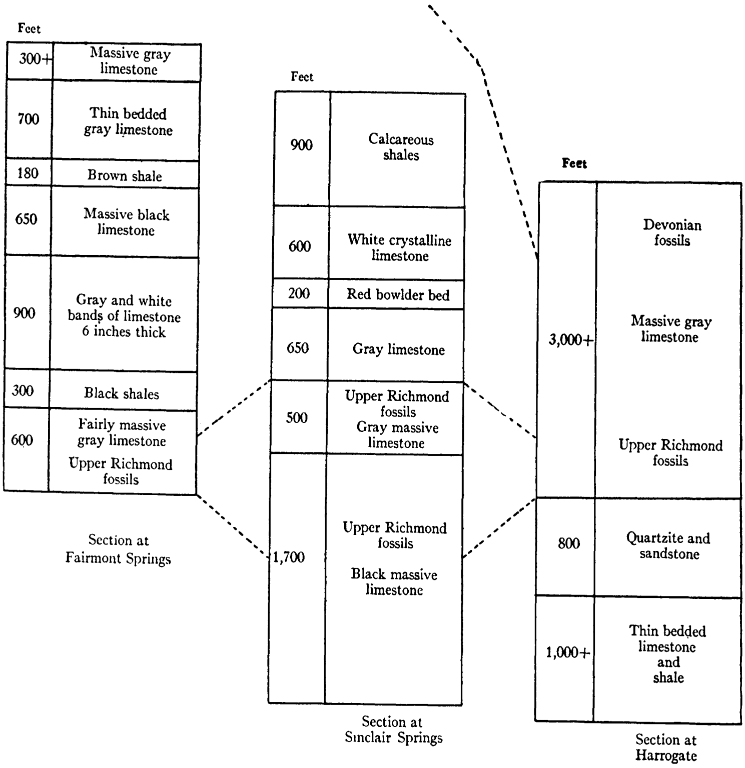
CORRELATION OF UNFOSSILIFEROUS FORMATIONS

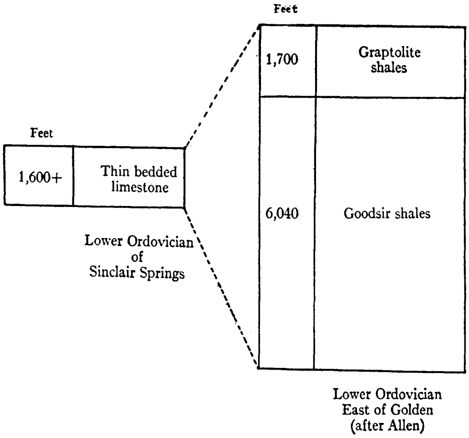
Correlation of the unfossiliferous formations over wide areas by lithological comparison has been resorted to frequently in the Cordillera. Dawson, McConnell, and others who made the pioneer surveys of the region relied especially on this method. Daly, as has been shown above, also correlated formations of widely separated portions on the same basis. Mistakes made in one of these attempts is illustrated by the recent findings concerning the Purcell series (p. 369).

The most detailed work on the unfossiliferous formations is that by Schofield in the Cranbrook area. Here the members of the Purcell series are mapped over an area of about 2,500 square miles. The characteristics of the different formations are such that they are likely to vary considerably, and to grade from one into another rather readily, so that with the great complication of the fault system in the region, a classification is extremely difficult.

From observations based chiefly on the fossiliferous formations, it appears that classification of the unfossiliferous formations is especially complicated by the extreme variability of the lithology, and of the metamorphic character of the formations along the trench.

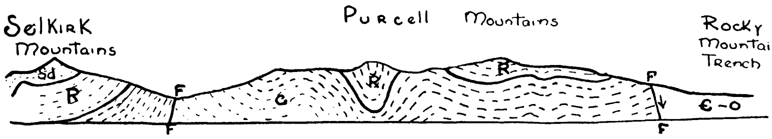
Lithological variations.—The lithological character of the different horizons in the Paleozoic was examined at several places along


Feet
300+
Massive gray limestone
700
Thin bedded gray limestone
180
Brown shale
650
Massive black limestone
900
Gray and white bands of limestone 6 inches thick
300
Black shales
600
Fairly massive gray limestone
Upper Richmond fossils
Section at Fairmont Springs
Feet
900
Calcareous shales
600
White crystalline limestone
200
Red bowlder bed
650
Gray limestone
500
Upper Richmond fossils
Gray massive limestone
1,700
Upper Richmond fossils
Black massive limestone
Section at Sinclair Springs
Feet
3,000+
Devonian fossils
Massive gray limestone
Upper Richmond fossils
800
Quartzite and sandstone
1,000+
Thin bedded limestone and shale
Section at Harrogate


Feet
1,600+
Thin bedded limestone
Lower Ordovician of Sinclair Springs
Feet
1,700
Graptolite shales
6,040
Goodsir shales
Lower Ordovician East of Golden (after Allen)

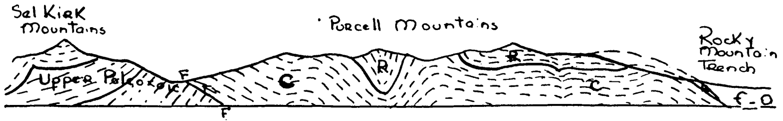
the east side of the trench. The change in the character of the beds containing the same faunal succession was the more notable because the formations were dominantly calcareous. A few sample sections (p. 373) will illustrate this point.

The lithology of a section east of Harrogate (Fig. 4) would indicate that there is an anticline or syncline forming the summit of the Beaverfoot Range, because of the apparent repetition of



€-O = Ordovician and Upper Cambrian
Sd = Sir Donald quartzite (Lower Cambrian)
R = Ross quartzite (Lower Cambrian and Beltian)
C = Cougar quartzite (Beltian)

Section along the main line of the Canadian Pacific Railway (after Daly)



€-O = Ordovician and Upper Cambrian
R = Ross Quartzite (Upper Cambrian?)
C = Cougar Quartzite (Cambrian?)

Same section revised

FIG. 4

the same formations in reverse order on the two sides. However, fossils proved that this reversed succession was a mere coincidence, and, as shown in the section, one side of the supposed anticline is Devonian and the other Ordovician. An occurrence of something of this sort in the Cranbrook area, or wherever else fossils were lacking, could very easily introduce error into the classification.

Metamorphic variations.—Metamorphic variations are especially important in the Purcell Range on the west side of the trench. This is perhaps especially true in the Cranbrook area, where there are more igneous intrusions than farther north, but even where the intrusions are absent metamorphism is found to vary greatly. In the Selkirk Range along the main line of the Canadian Pacific Railway, where there are no intrusives, the upper Paleozoic Laurie formation contains the same type of semi-metamorphic beds as are found farther east in the lower portions of the Cambrian. Many of the upper Paleozoic rocks of the Arrow Lake region are more metamorphosed than the pre-Cambrian (or early Cambrian) beds to the east in the Cranbrook area. This last case is probably explained by contact metamorphism.

A quartz grit having well-rounded quartz pebbles and a calcareous cement was found in several places along the west side of the trench in the vicinity of Lake Windermere. This formation was associated with argillaceous rocks which varied from shales to schists in the different localities, although it most likely represents the same horizon because of its very distinctive characteristics, which were not found in any other formation.

At Sinclair Springs there is a bed of highly crystalline limestone which is higher in the stratigraphic series than another limestone which is not crystalline. So many similar cases were found that it seems as though the anamorphic influences along the trench were very irregular. The cause of this irregularity is varied. In the southern Purcells, the intrusions are chiefly responsible. Farther north the intrusives rarely appear at the surface, but their presence below the surface is shown by the hydrothermal alteration of the rocks in many places along the west side of the trench. In the northern portion, however, the most important anamorphic results are connected with diastrophic movements. In the vicinity of large faults the alteration is often more pronounced than elsewhere. The Purcell Range was probably deformed at two periods[1] so that the formations on that side would tend to be differently metamorphosed from those of corresponding age on the other side. At present the exposed pre-Cambrian and later formations are found at the same general level, but formerly the pre-Cambrian was more deeply buried. As deformation went on, the pre-Cambrian was brought gradually toward the level of the younger formations by folding and faulting. After the two reached the same level, metamorphism would tend to be somewhat equal in effects on each. Before that time the more deeply buried pre-Cambrian would tend to be more severely metamorphosed unless it was below the zone in which the most effective compression was being concentrated. Further confusion in regard to differential metamorphism may be produced by the cutting of great valleys in the rising mountain ranges. Along the lines of these valleys the overburden is less, and therefore there would be less severe metamorphism. Thus the amount of metamorphism of a local series of rocks in this general region can only be used to tell its relative age in exceptional cases.

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[1] S. J. Schofield, *Geol. Surv. Can. Mem. 76,* p. 101.

The foregoing consideration of the varying character of the lithology and metamorphism is intended to show how extremely difficult it is to correlate unfossiliferous formations in a mountainous region. Attempts at such correlations are of course suggestive, but they should be duly qualified.